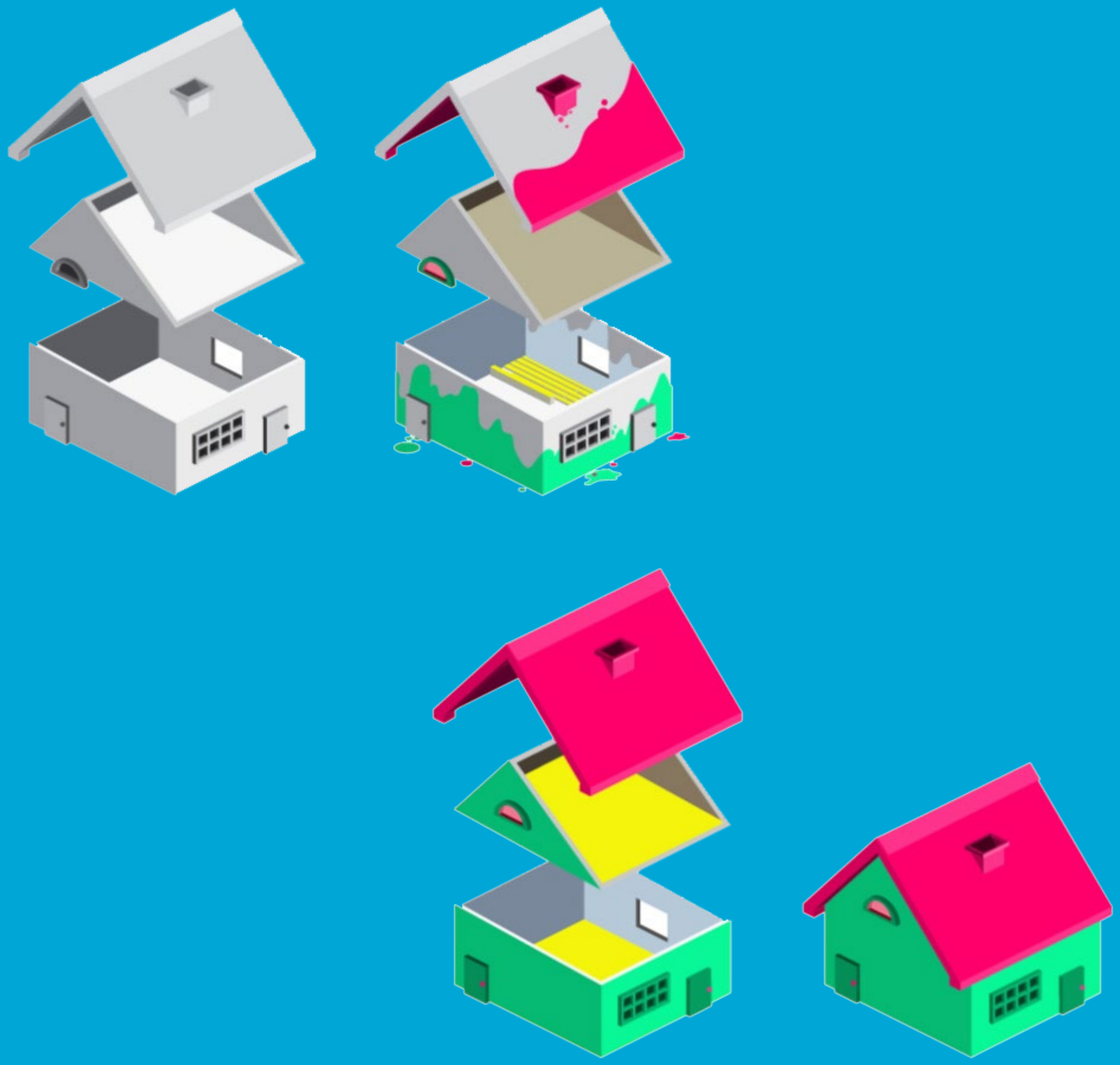
Date: 18 June 2024

P5 presentation

Nefeli Karadedou_ 5629535

Retrofitting planning optimization



MSc in Architecture, Urbanism & Building Sciences
(Building Technology Track)

Main Mentor

Charalampos Andriotis

Second Mentor

Michela Turrin

Consultants

Pablo Morato Dominguez ,

Lisa-Marie Mueller , Anna-Maria Koniari

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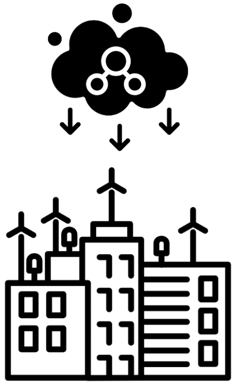
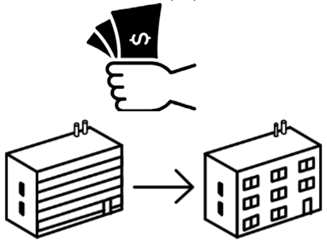
Problem statement

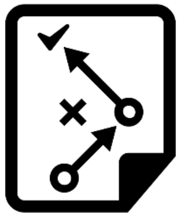
Buildings fleet is ageing (2)



EU aims to decarbonize building stock (1) with renovations

Economic reasons are some of the bottlenecks of performing retrofitting in residential buildings (3)





Optimal Planning of Renovations has potential of increasing the rate and performance of the building stock

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(1) https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en
(2) OVERVIEW | Decarbonising the non-residential building stock | BUILD UP (europa.eu)
(3) New step-by-step retrofitting model for delivering optimum timing

Research Gap

‘Not enough research has been conducted in Building Retrofitting Planning Optimization’

Retrofitting measures

Renovation or Retrofitting is the act of adding or replacement of building elements , aiming to better the condition of the building (1)

Envelop measures

- Change roof insulation
- Change windows
- Change ground floor insulation
- Change exterior wall insulation

Technical measures

- Install RES
- Change heating system
- Add/Change mechanical ventilation
- Add/Change cooling system

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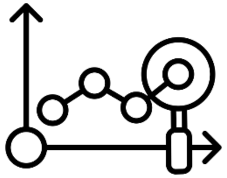
(1) *I. Maia, L. Kranzl, and A. Müller, "New step-by-step retrofitting model for delivering optimum timing,"*

Planning

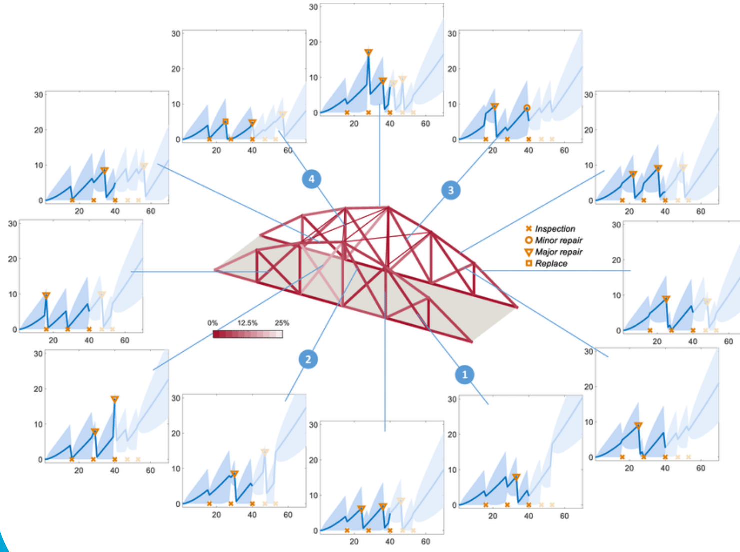
"The main objective of a planned maintenance policy is to increase the performance of the building components and, at the same time, reduce the likelihood of problems that can occur during the service life" (2).

Predetermined

Condition based



Predictive



(2) C. Ferreira, A. Silva, J. de Brito, and I. Flores-Colen, "Maintainability of Buildings' Envelope," in Springer Series in Reliability Engineering, Springer Science and Business Media Deutschland GmbH, 2023, pp. 63–115. doi: 10.1007/978-3-031-14767-8_4.

(3)Andriotis, C. P., & Papakonstantinou, K. G. (2018). Managing engineering systems with large state and action spaces through deep reinforcement learning. ResearchGate. https://www.researchgate.net/publication/328781547_Managing_engineering_systems_with_large_state_and_action_spaces_through_deep_reinforcement_learning

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Goal

Investigate a methodology for predictive retrofitting planning optimization

Problem statement

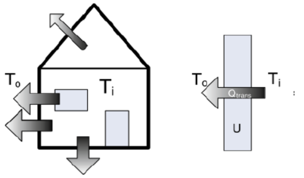
- Define an objective

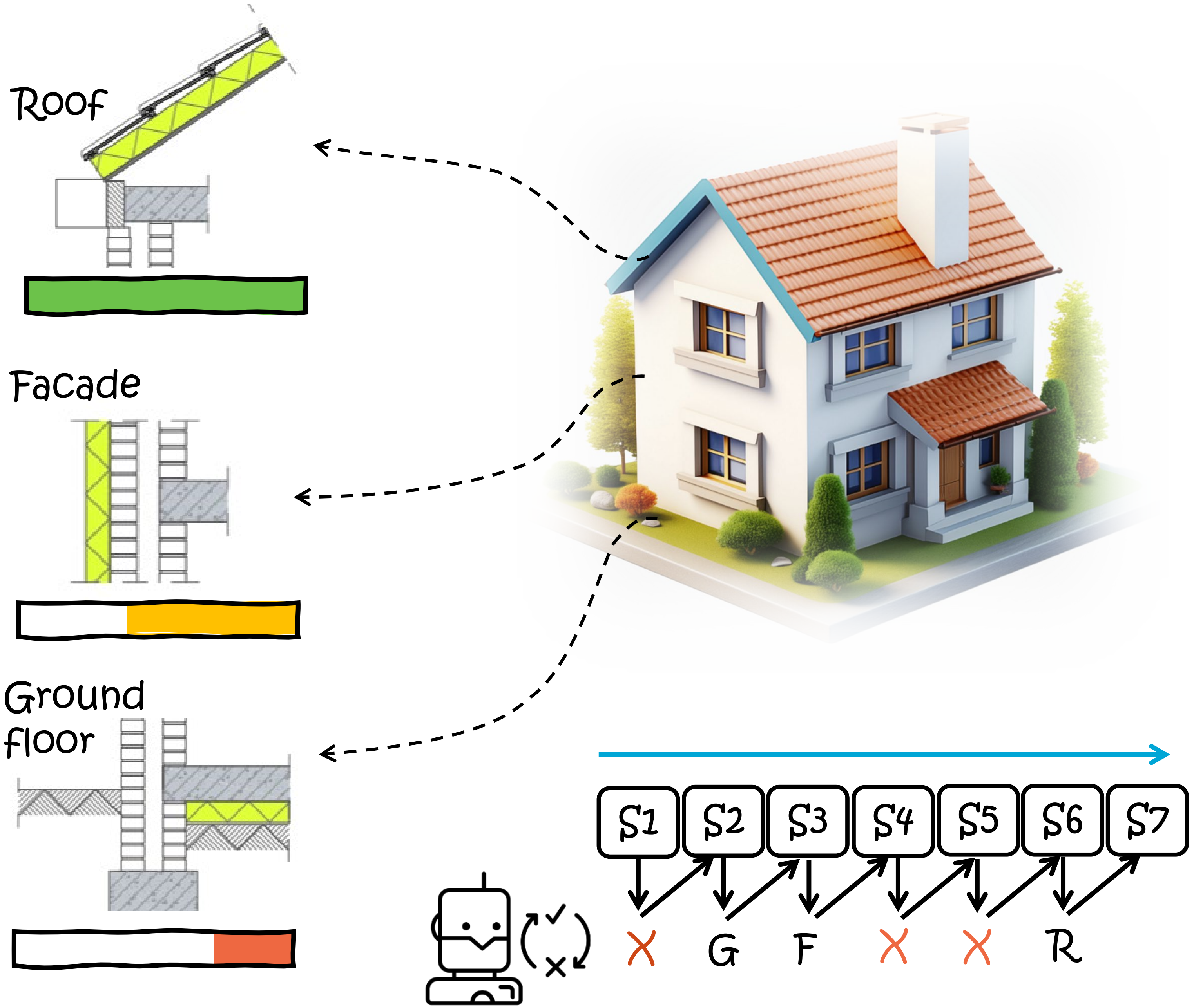
$$minCost = \sum_{t=0}^{60} (IC_t + EC_t)$$

- IC_t = investment cost of retrofitting measures [EUR];
- EC_t = annual running energy costs [EUR/a]

- Consider elements that might degrade

Ageing insulation allows heat escape building more quickly raising the heating energy demand





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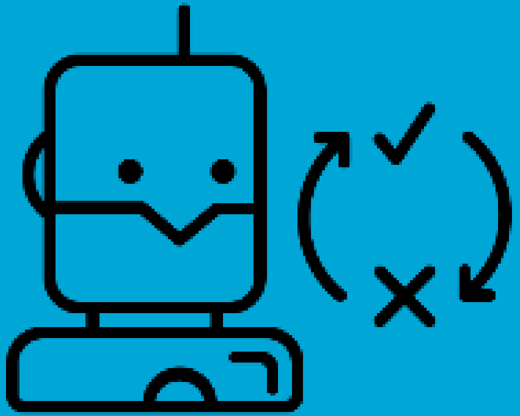
Algorithms for planning problems

SARSA

Q-Learning



Linear Programming

Policy Iteration

Value Iteration

Others…

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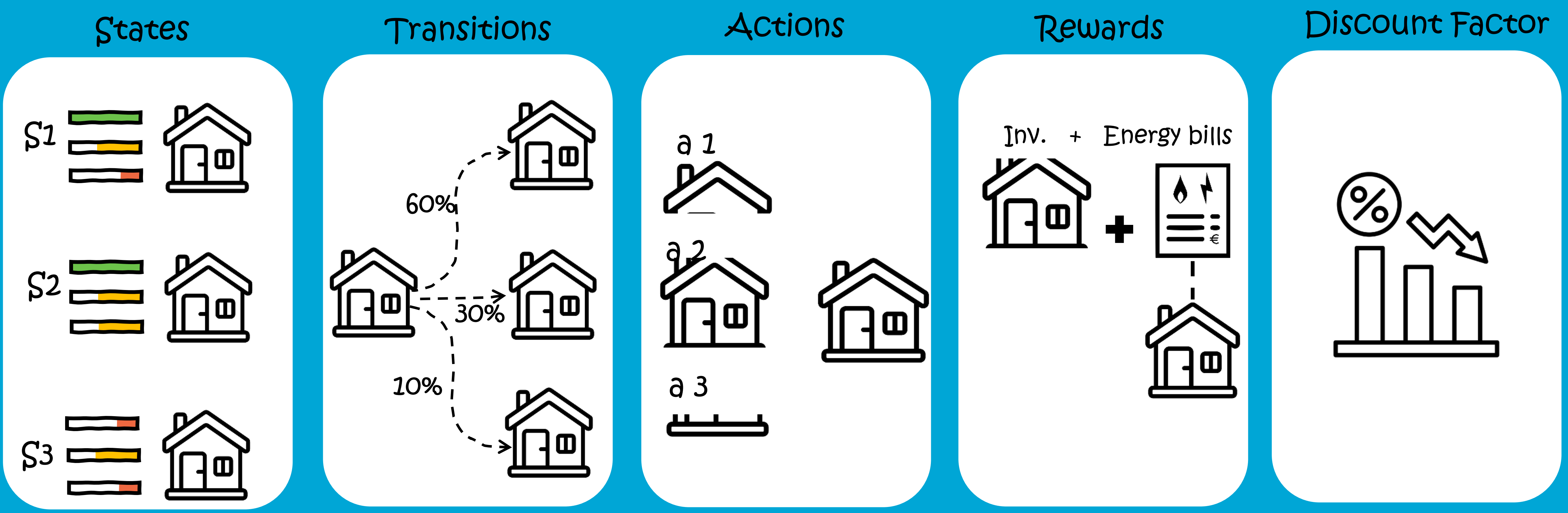
Markov Decision Process

= Described by the tuple (S,A,T,R, g)

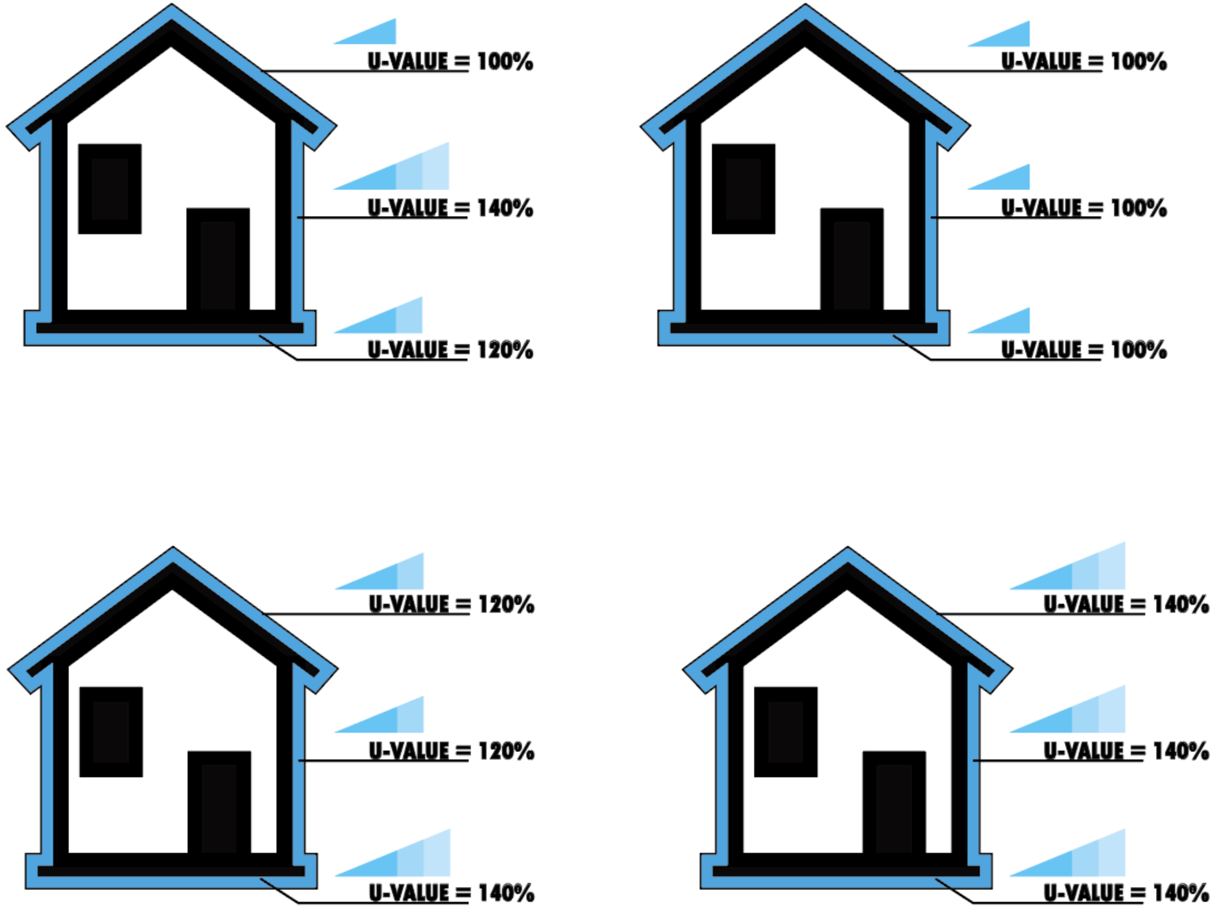


States (S)

- $S \rightarrow (t, \; r, f, g, \; r_{age}, f_{age}, g_{age})$

t	r, f, g	$r_{age}, f_{age}, g_{age}$
0	0%	0
10	20%	10
20	40%	20
.		.
.		.
.		.
60		60

Total # of states: ~34K



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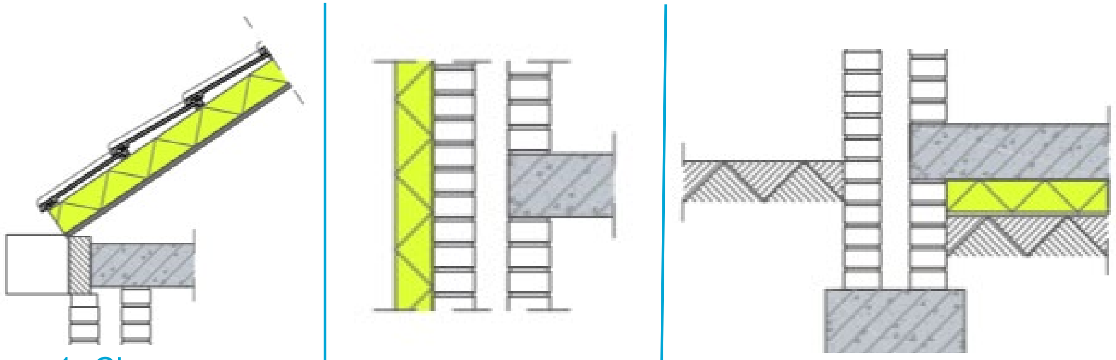
Actions (A)



Action

a1- Change Roof Insulation

a2- Change Wall Insulation

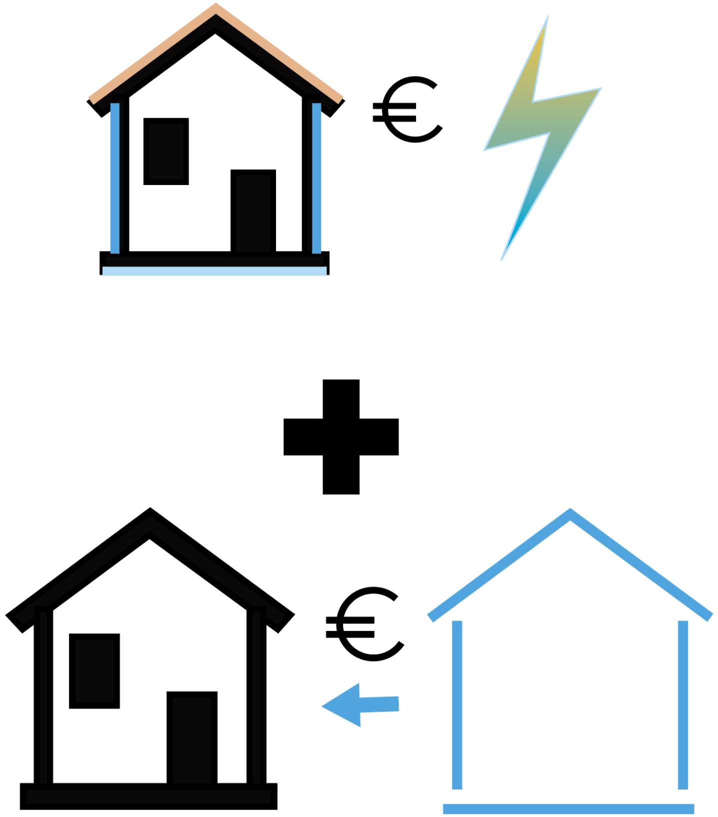
a3- Change Ground Floor Insulation

		Investment costs
a0	Do nothing	0
a1	Change Roof Insulation	13407
a2	Change Façade Insulation	43533
a3	Change Cellar Floor Insulation	2614
a4	Change Roof and Cellar	16021
a5	Change Facade and Cellar	46147
a6	Change Roof and Facade	56940
a7	Change All	59554

(1-3) M. Sewnath, “Title ’ ’Towards Zero Carbon: A Comprehensive Evaluation of Conventional Renovation Strategies for Terraced Houses, Using Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) to Enhance Decision-Making Supportaccompanied by the design of a tool Personal details.”

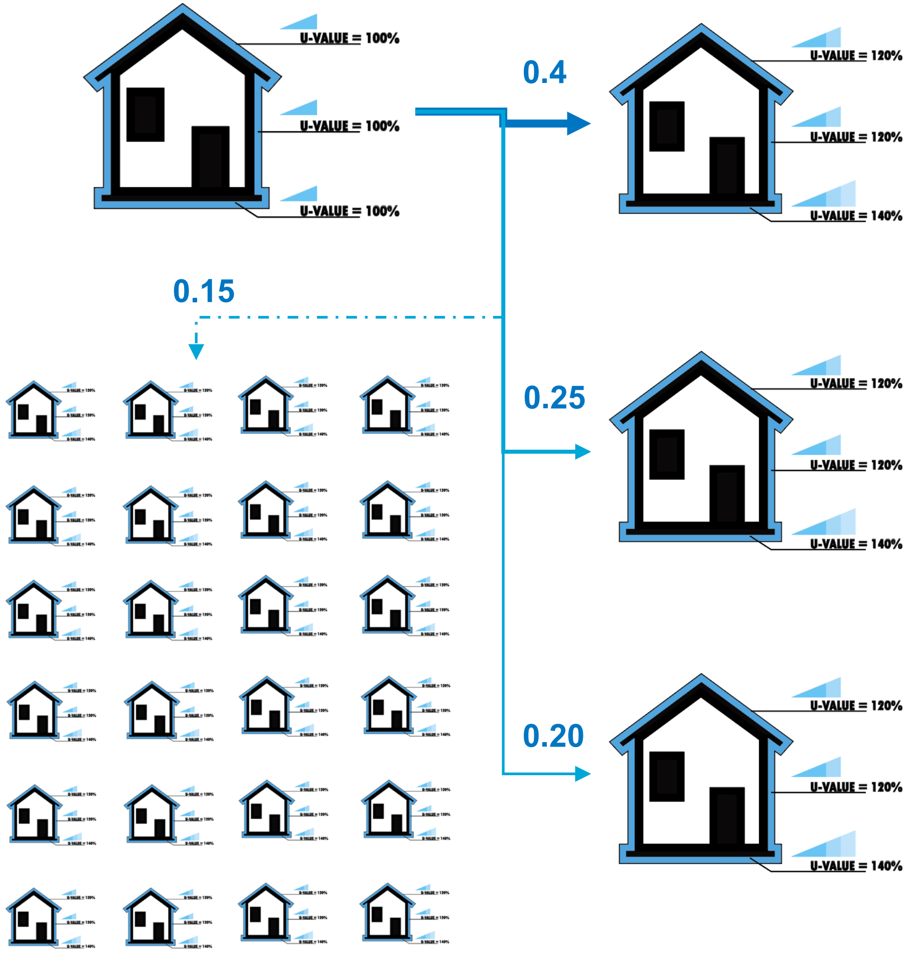
Reward(R)

$$R(s,a)$$



HOUSE STATE (ROOF DEG, FAÇADE DEG, GROUND FLOOR DEG)	Energy demand [kWh/m2]	Euros in bills	Rewards
(R: 0%, F: 0%, G: 0%)	165.72	14620.5	Euros in bills + a
(R: 0%, F: 0%, G: 20%)	166.13	14656.6	Euros in bills + a
(R: 0%, F: 0%, G: 40%)	166.54	14692.4	Euros in bills + a
(R: 0%, F: 20%, G: 0%)	169.17	14924.4	Euros in bills + a
(R: 0%, F: 20%, G: 20%)	169.57	14960.0	Euros in bills + a
. . .	. . .	. . .	. . .

Transition probabilities (P)



- $P \rightarrow P(s'|s, a) \rightarrow P_r \cup P_f \cup P_g$

- Transitions are stochastic
- Transitions are non-stationary and they depend on the age factor

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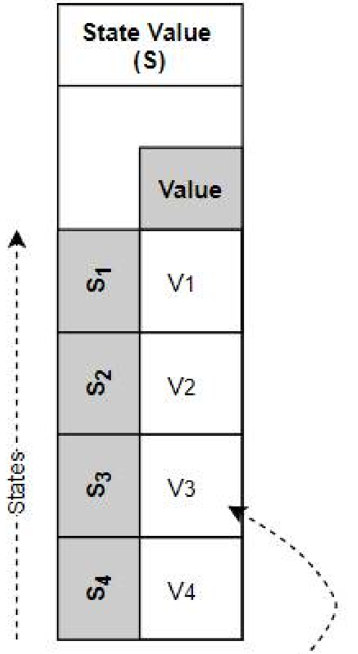
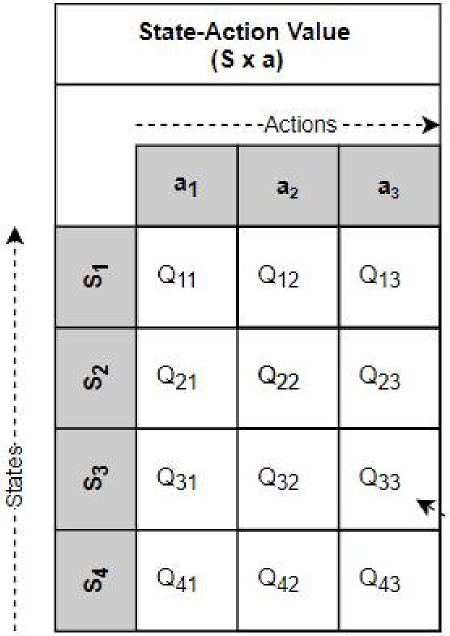
Value Iteration

$$V^*(s) = \max_a Q^*(s,a)$$

$$Q^*(s,a) = \sum_{s'} P(s'|s,a)[R(s,a,s') + \gamma V^*(s')]$$



$V(S_3)$ ie. Expected Return from State S_3 by following Policy π



$Q(S_3, a_3)$ ie. Expected Return by taki[ng] Action a_3 from State S_3 and following Policy π after that

$$\pi^* = \arg\max_a Q(s,a)$$

Policy X

Policy Table

	a1	a2
S1	0.4	0.6
S2	0.2	0.8
S3	0.7	0.3
S4	0.6	0.4
S5	0.5	0.5

State Value and State-Action Value

	V
S1	1.6
S2	1.4
S3	1.7
S4	2.3
S5	0.9

	a1	a2
S1	1.8	1.2
S2	1.5	1.3
S3	1.2	1.6
S4	2.1	1.8
S5	0.8	1.0

Policy Y

Policy Table

	a1	a2
S1	0.6	0.4
S2	0.3	0.7
S3	0.7	0.3
S4	0.5	0.5
S5	0.2	0.8

State Value and State-Action Value

	V
S1	2.4
S2	2.1
S3	2.5
S4	2.9
S5	1.9

	a1	a2
S1	2.8	2.2
S2	2.5	1.9
S3	2.3	1.8
S4	2.7	3.0
S5	1.8	2.1

Policy Z

Policy Table

	a1	a2
S1	0.0	1.0
S2	0.0	1.0
S3	1.0	0.0
S4	1.0	0.0
S5	0.0	1.0

State Value and State-Action Value

	V
S1	3.1
S2	3.3
S3	3.5
S4	2.9
S5	2.8

	a1	a2
S1	3.0	3.3
S2	3.2	3.4
S3	3.6	3.1
S4	3.0	2.8
S5	2.8	3.2

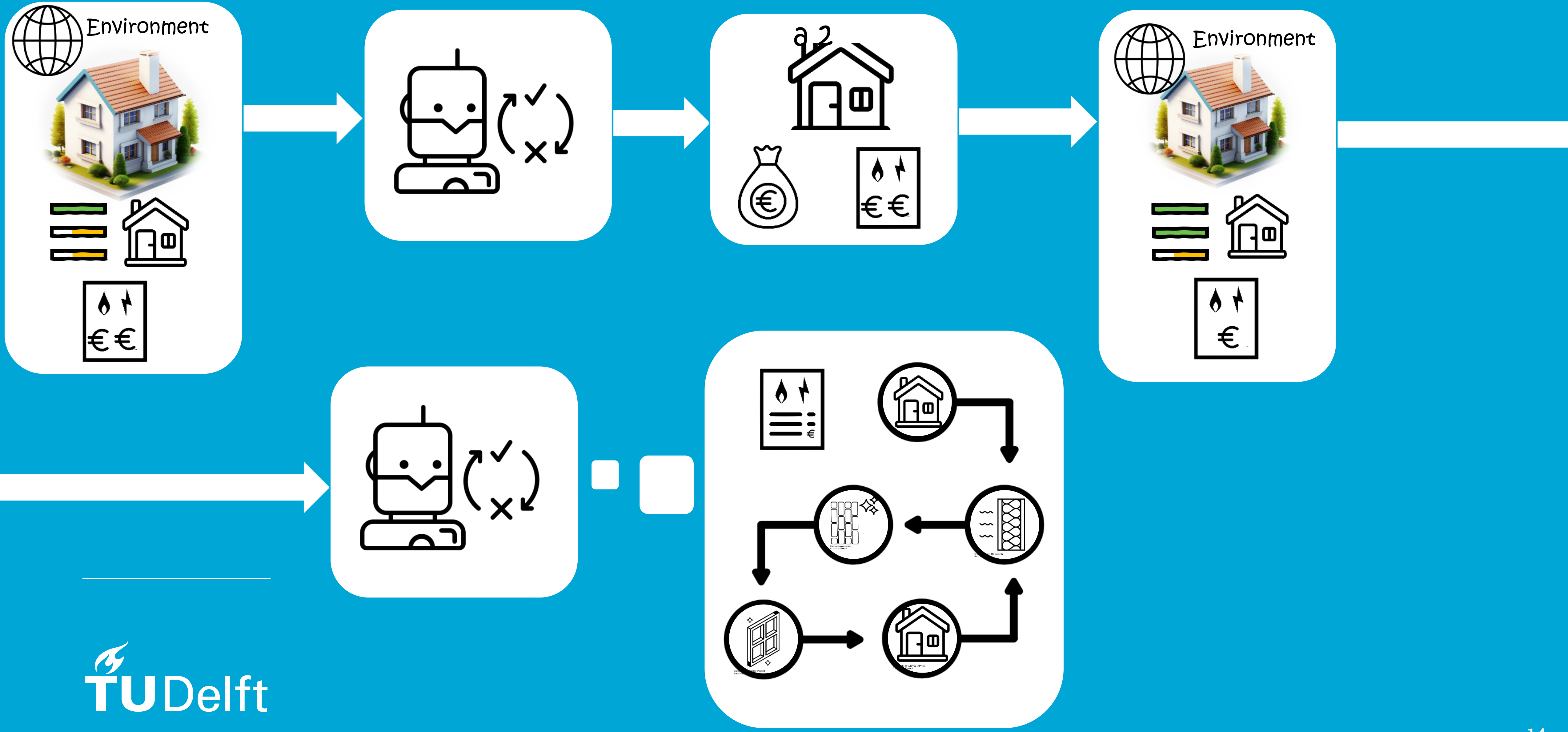
Optimal State Value and Optimal State-Action Value

The return G_t is the total discounted reward from time-step t

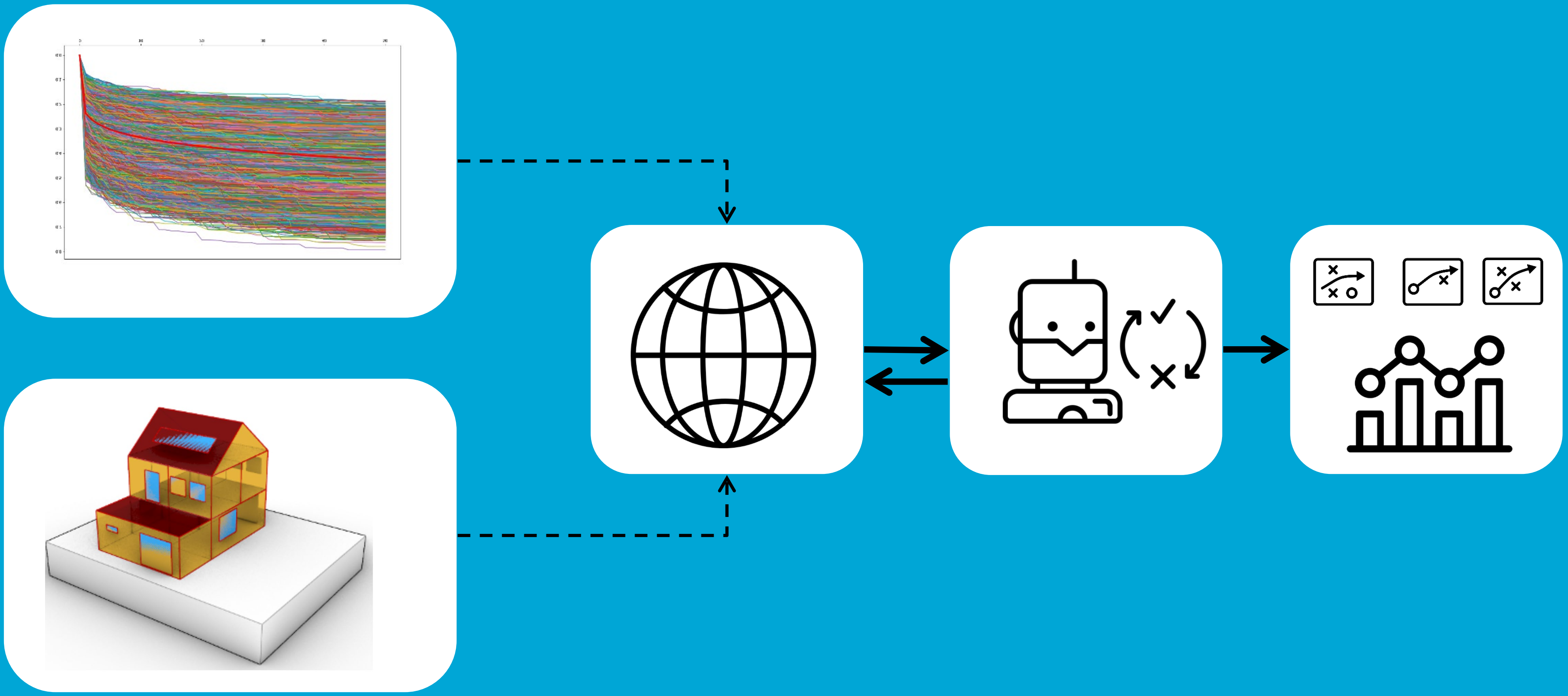
$$G_t = R_{t+1} + \gamma R_{t+2} + \cdots = \sum_{k=0}^{\infty} \gamma^k R_{t+k+1}$$

https://ketanhdoshi.github.io/Reinforcement-Learning-Model/

Optimization Methodology



Project Workflow



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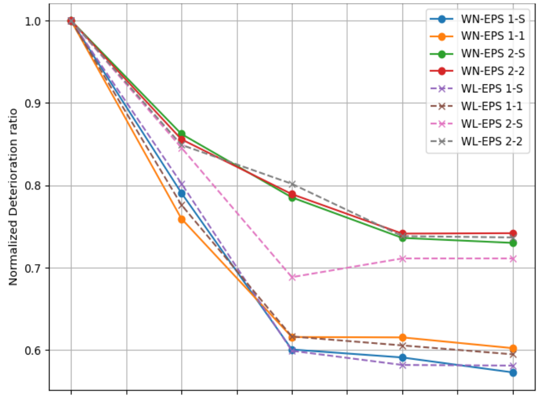
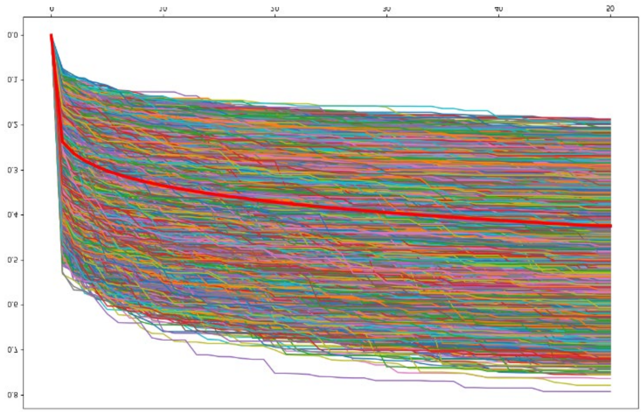
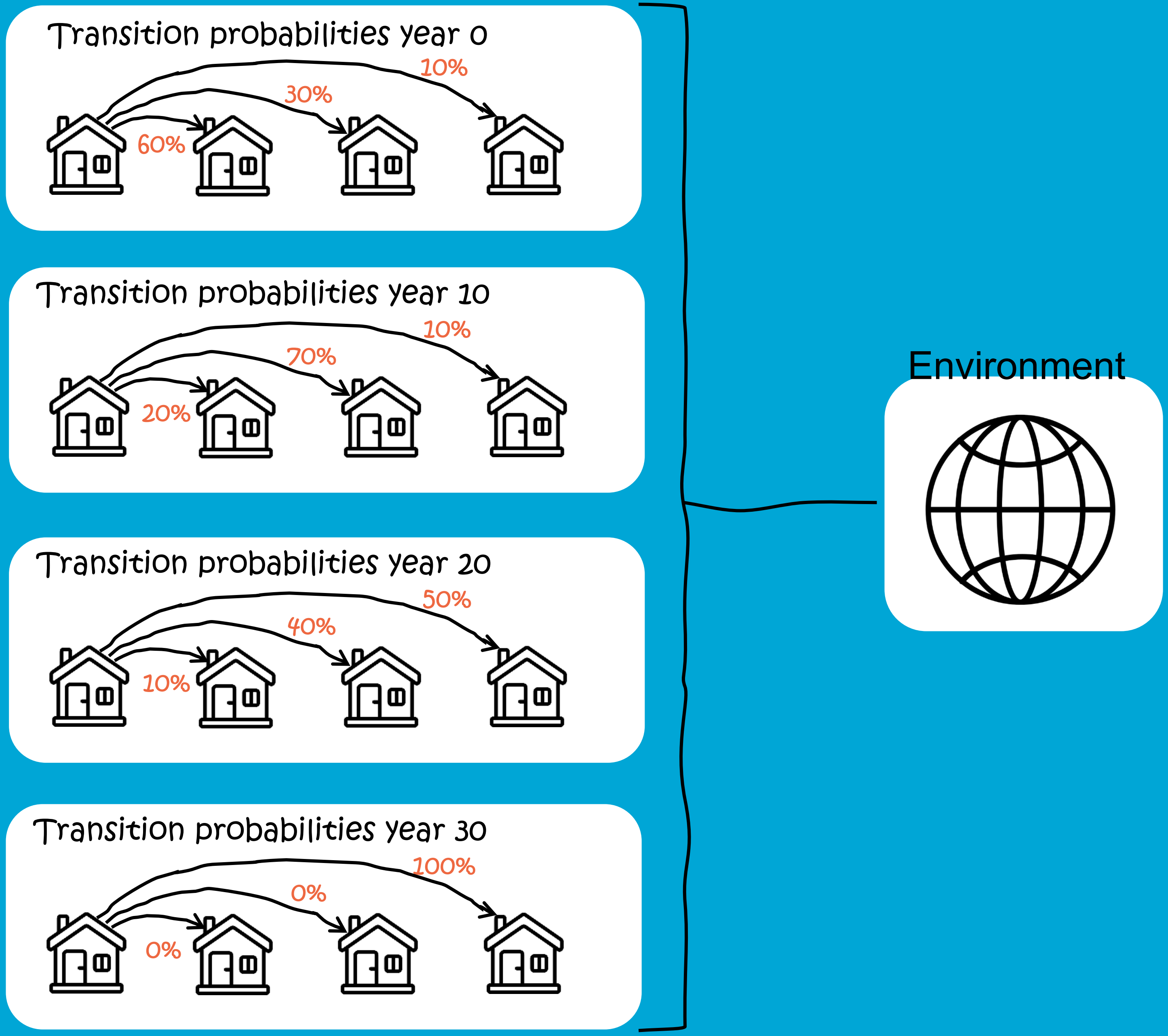
Transition Probabilities Generation

EPS insulation thermal resistance

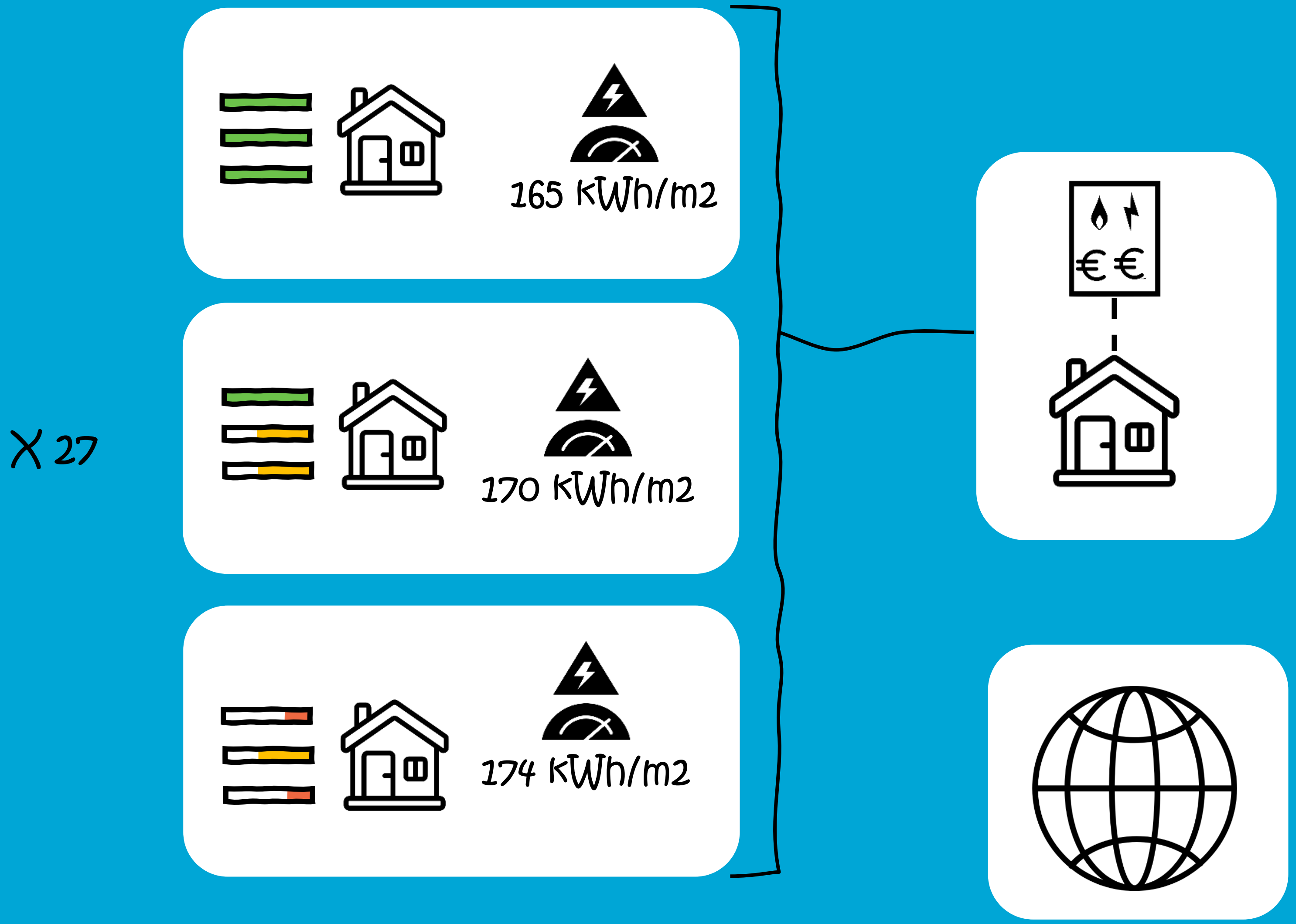


Degradation scenarios generation





Building energy degradation modelling



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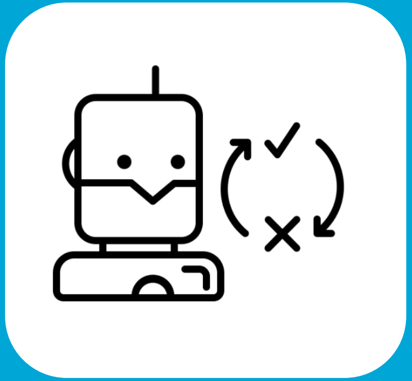
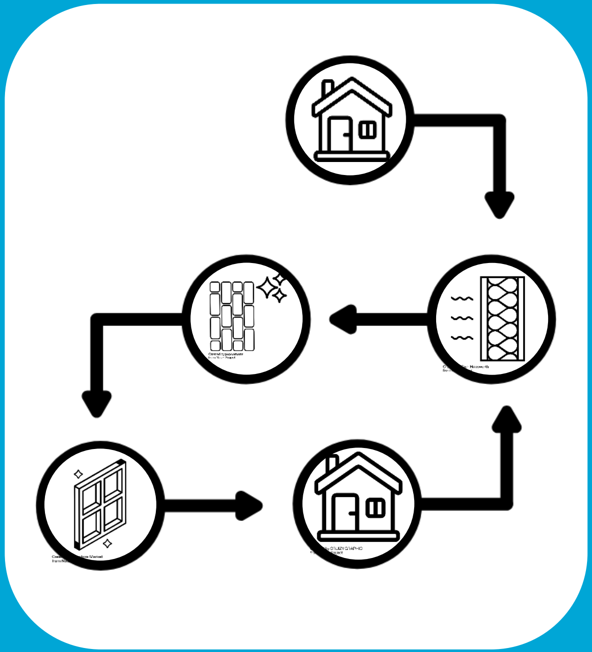
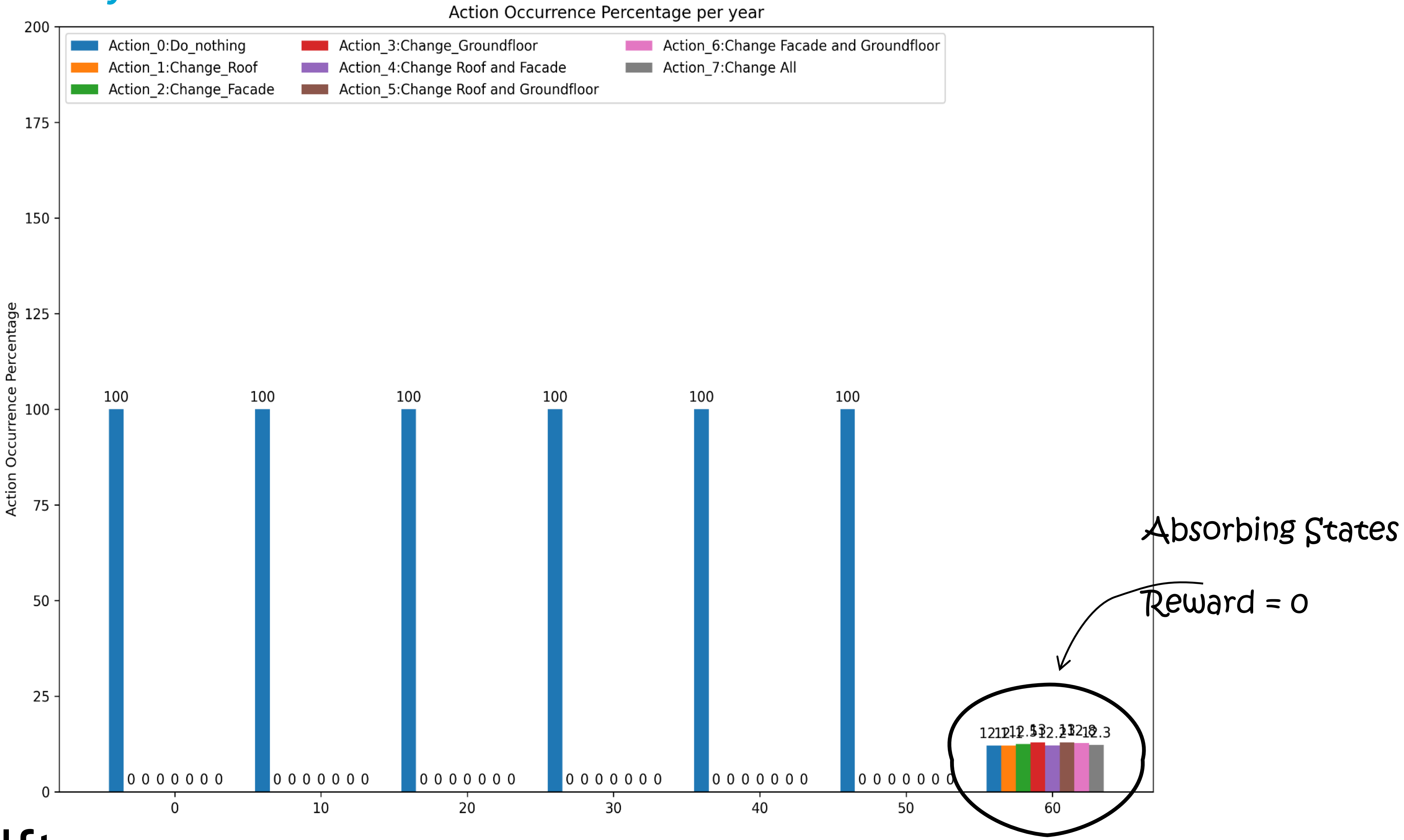
Results

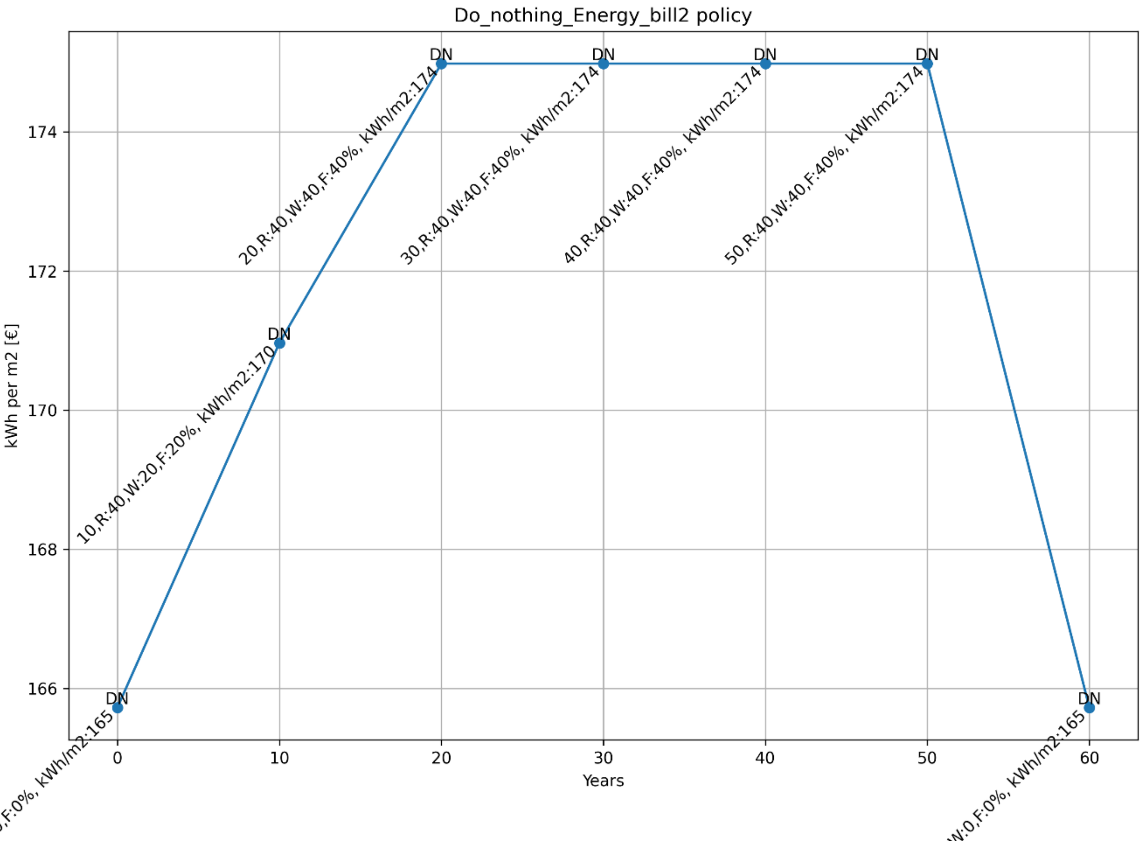


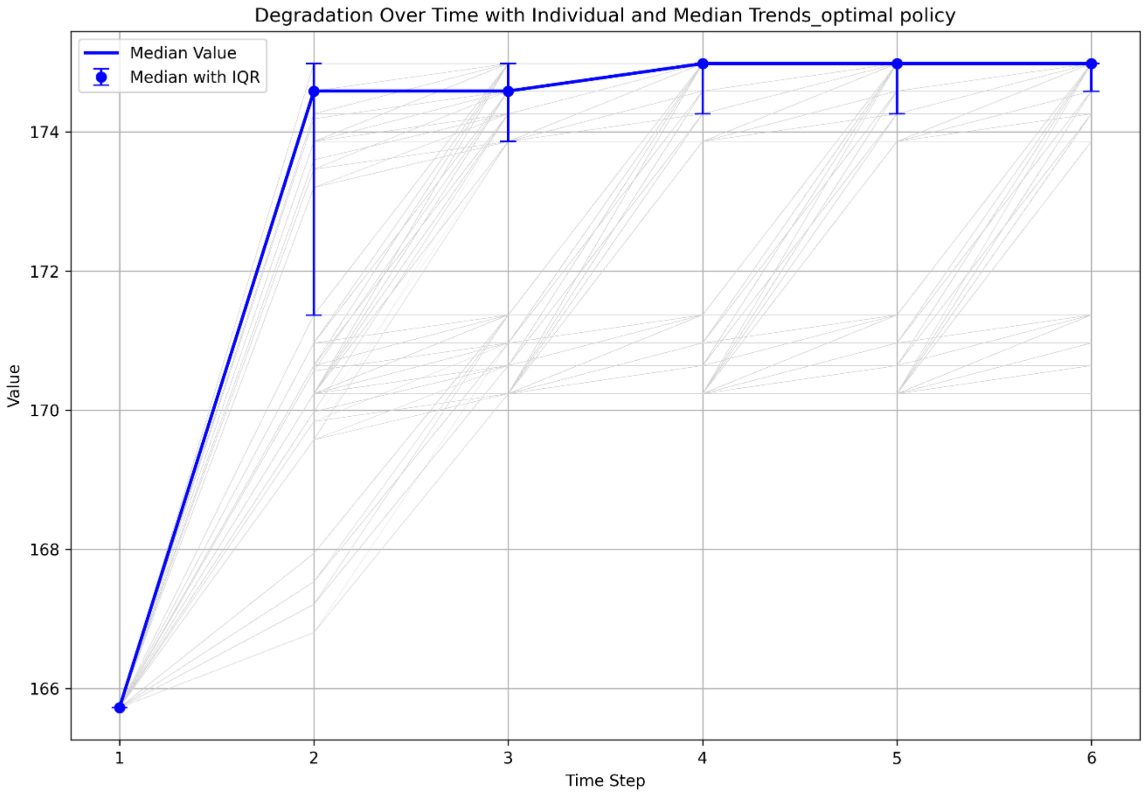


Optimal Policy



Optimal Policy Plots





- The costs of taking an action overpass the costs of energy bills

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***EU** aims*
to achieve a fully decarbonized building stock by 2050 (1)

↔

Economic reasons is one of the bottlenecks of **building owners** performing retrofitting in residential buildings (3)

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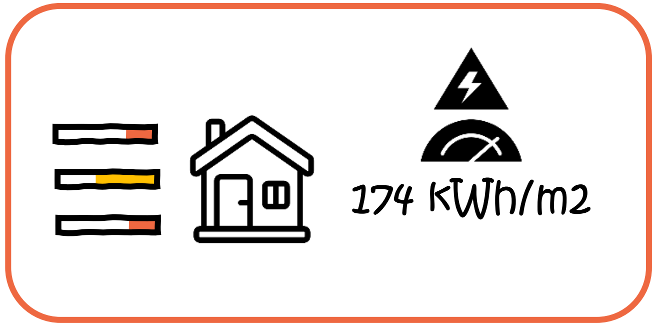
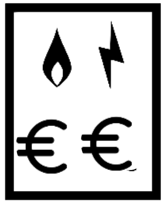
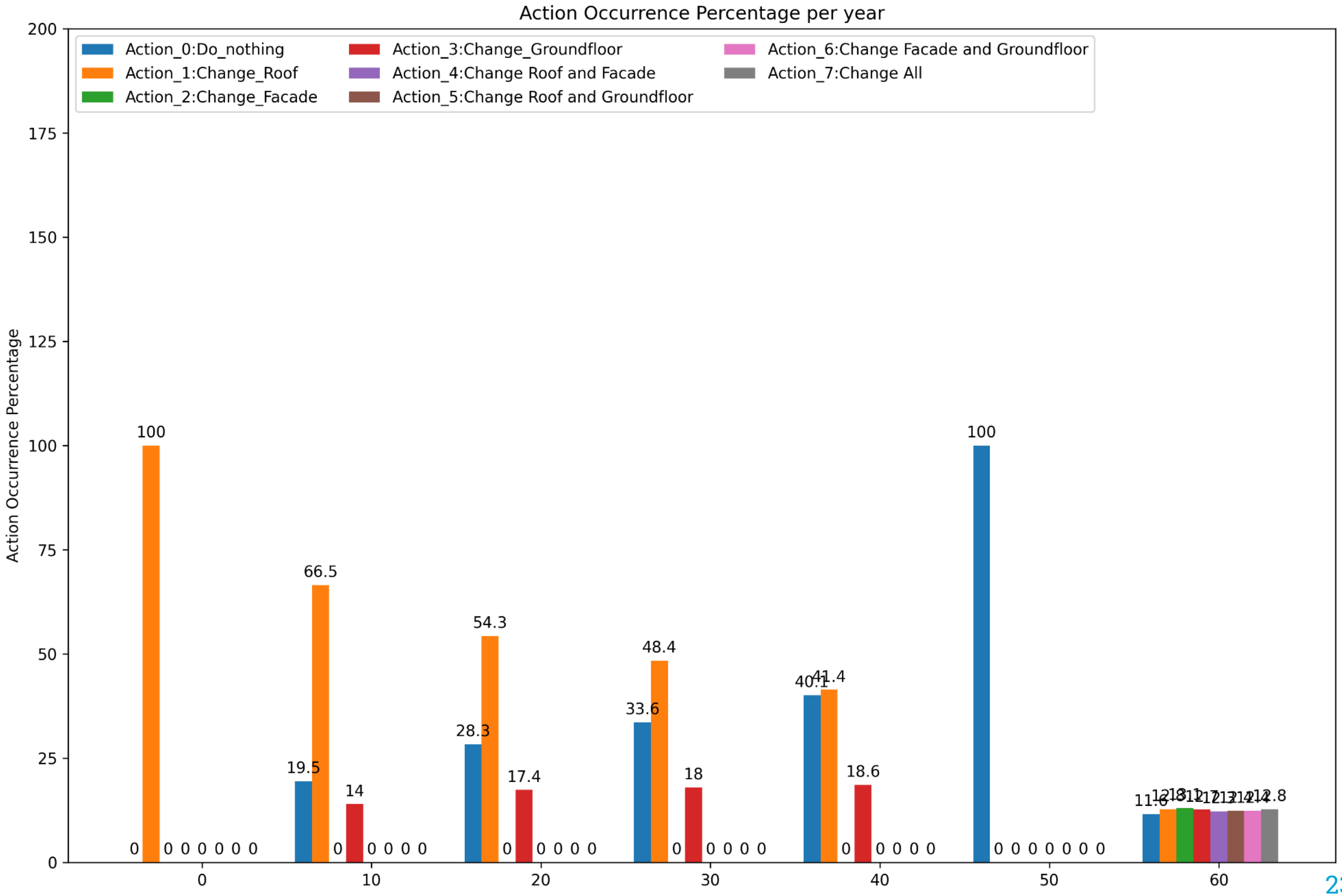
Optimal policy from penalty

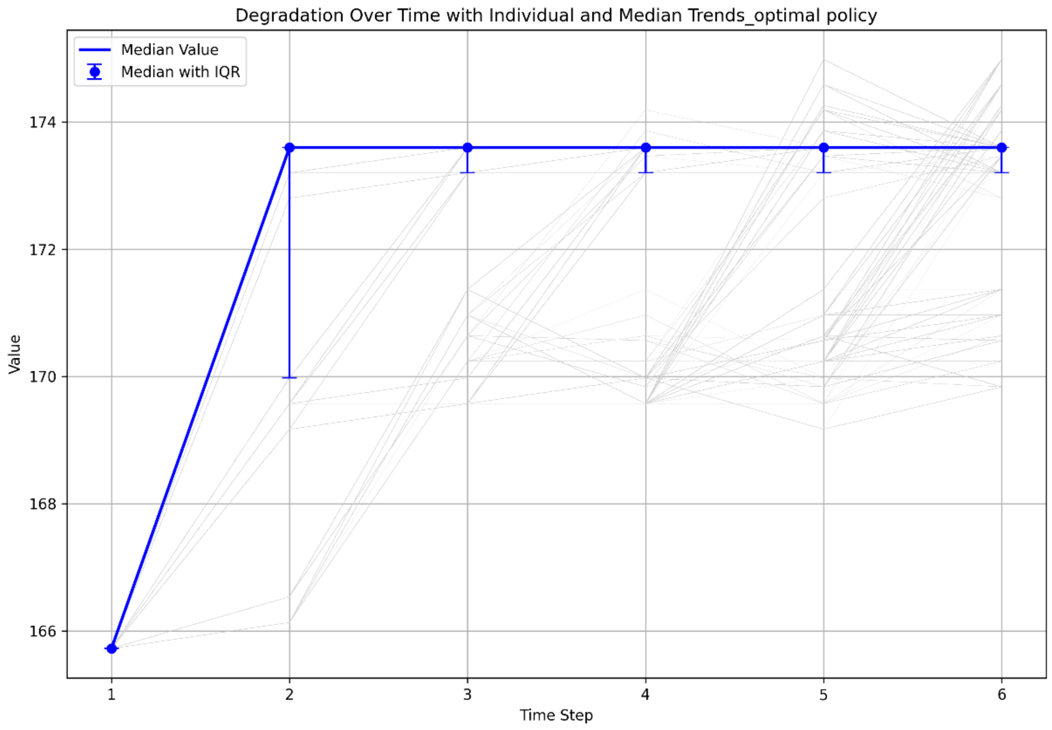


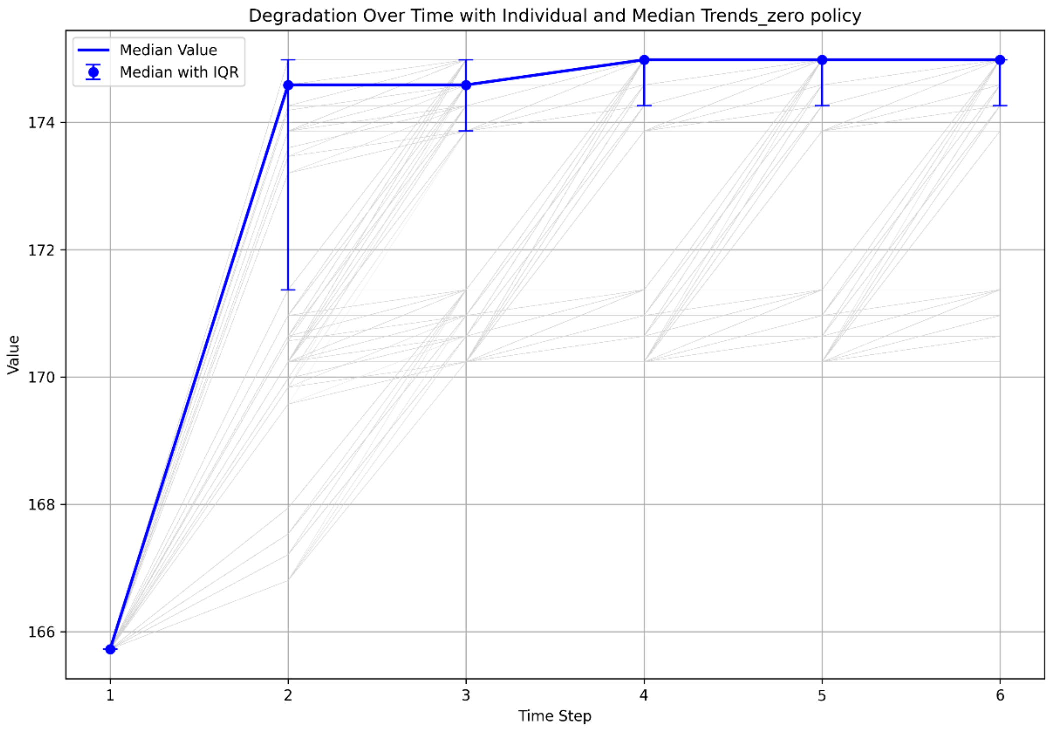
X 2 Energy bills



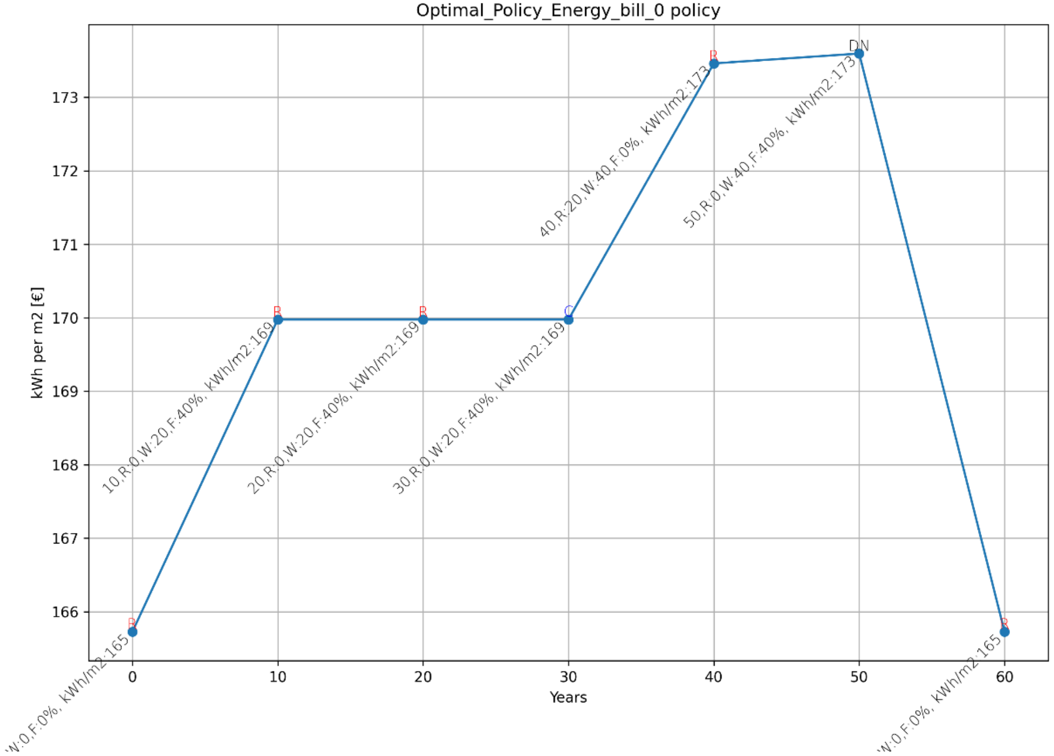


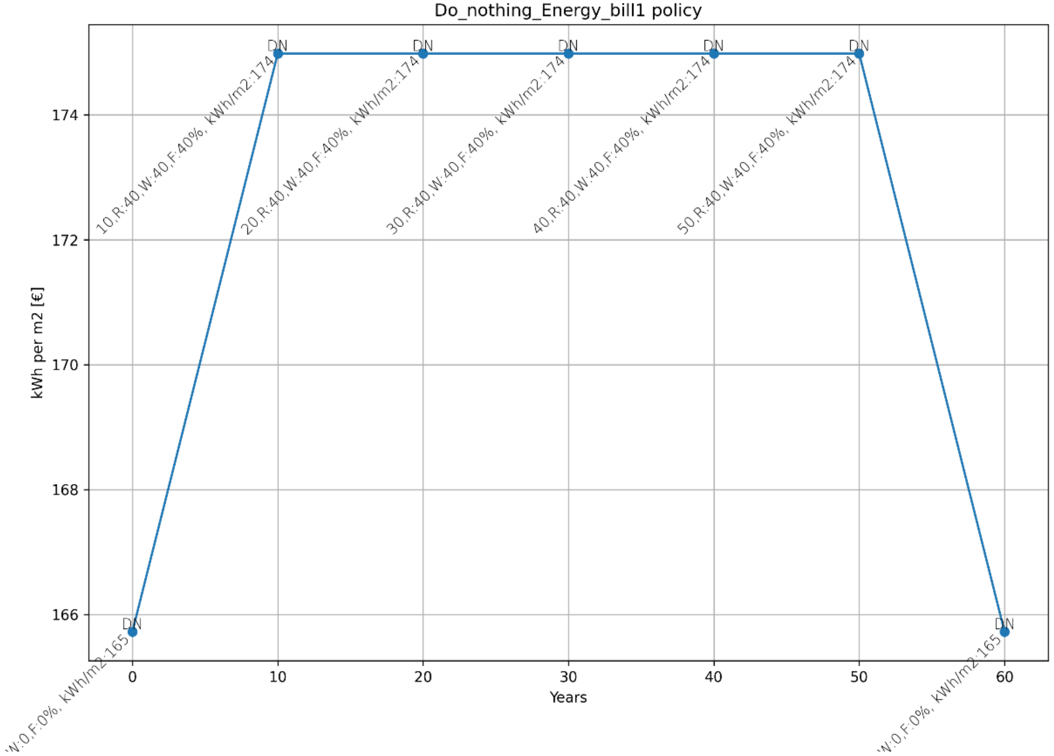
Problem statement



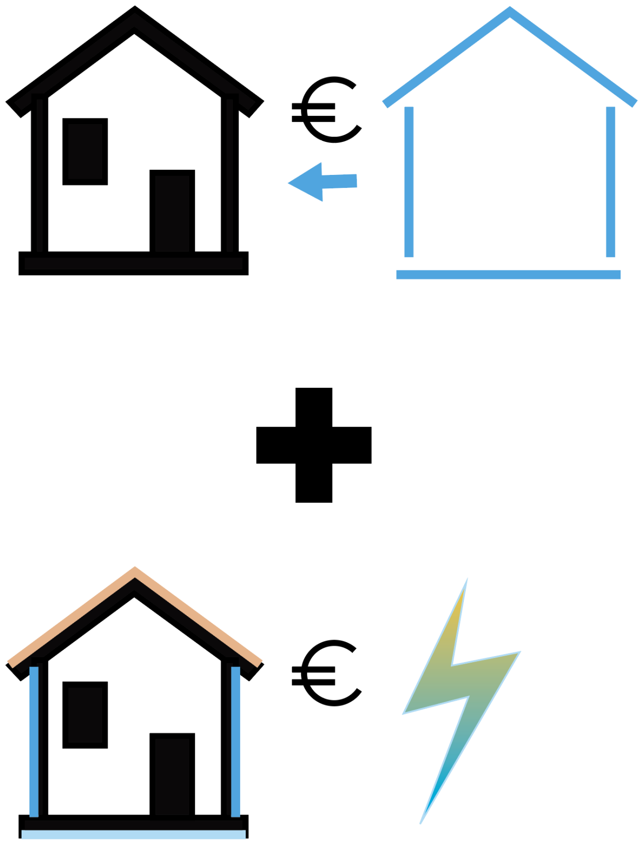


Problem statement





Rewards



HOUSE STATE (ROOF DEG, FAÇADE DEG, GROUND FLOOR DEG)	Energy demand [kWh/m2]	Euros in bills	Rewards
(R: 20%, F: 40%, G: 40%)	174.25	15373.2	**2 x** Euros in bills + a
. . .	. . .	. . .	. . .
(R: 40%, F: 20%, G: 40%)	171.36	15118.3	Euros in bills + a
(R: 40%, F: 40%, G: 0%)	174.18	15367.0	**2 x** Euros in bills + a
(R: 40%, F: 40%, G: 20%)	174.58	15402.1	**2 x** Euros in bills + a
(R: 40%, F: 40%, G: 40%)	174.98	15436.9	**2 x** Euros in bills + a

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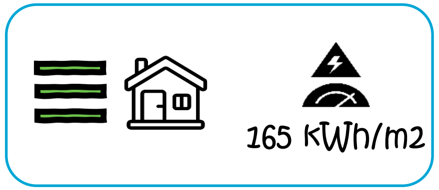
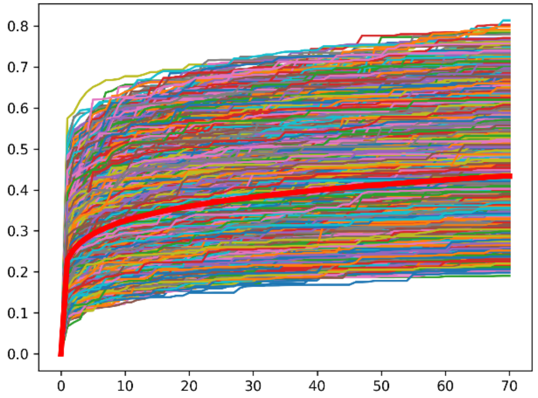
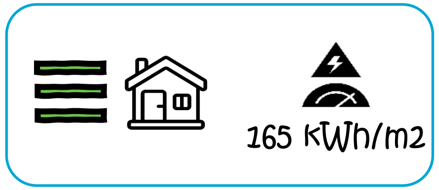
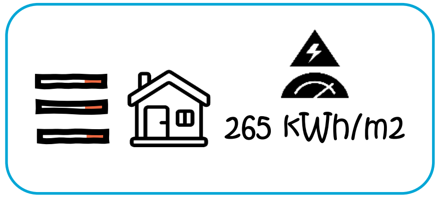
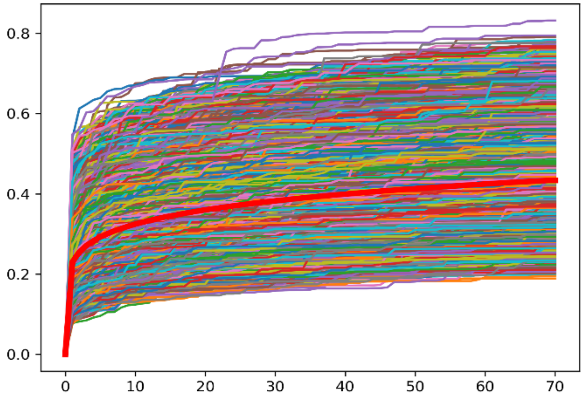
Comparison between 5% and 60% energy demand change

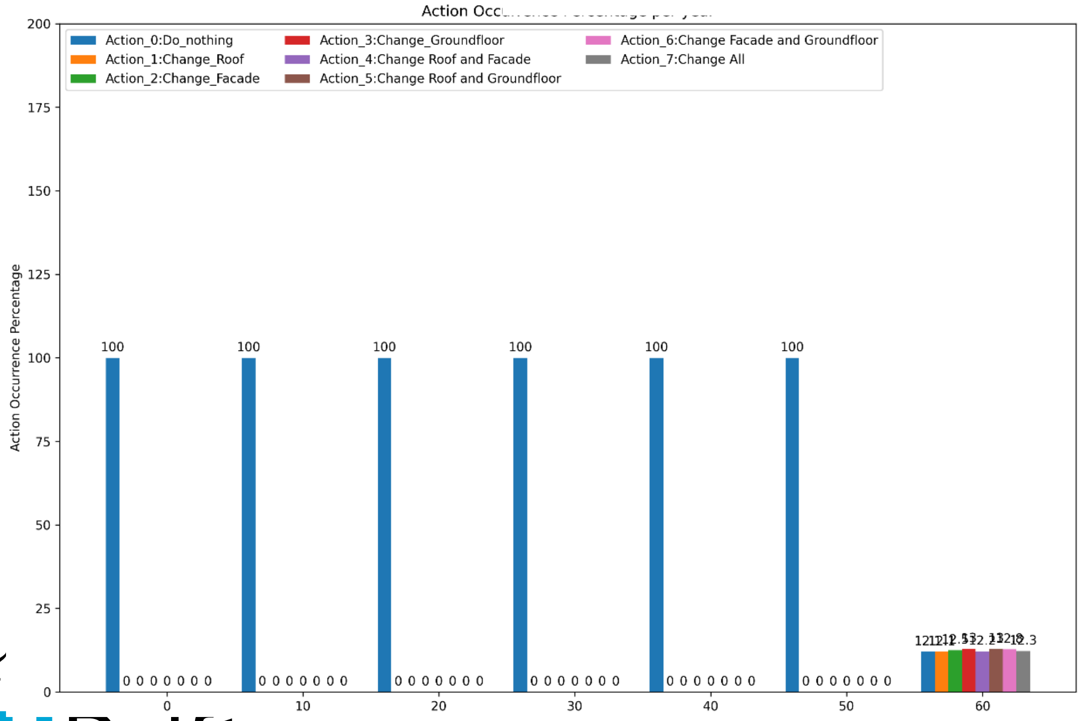


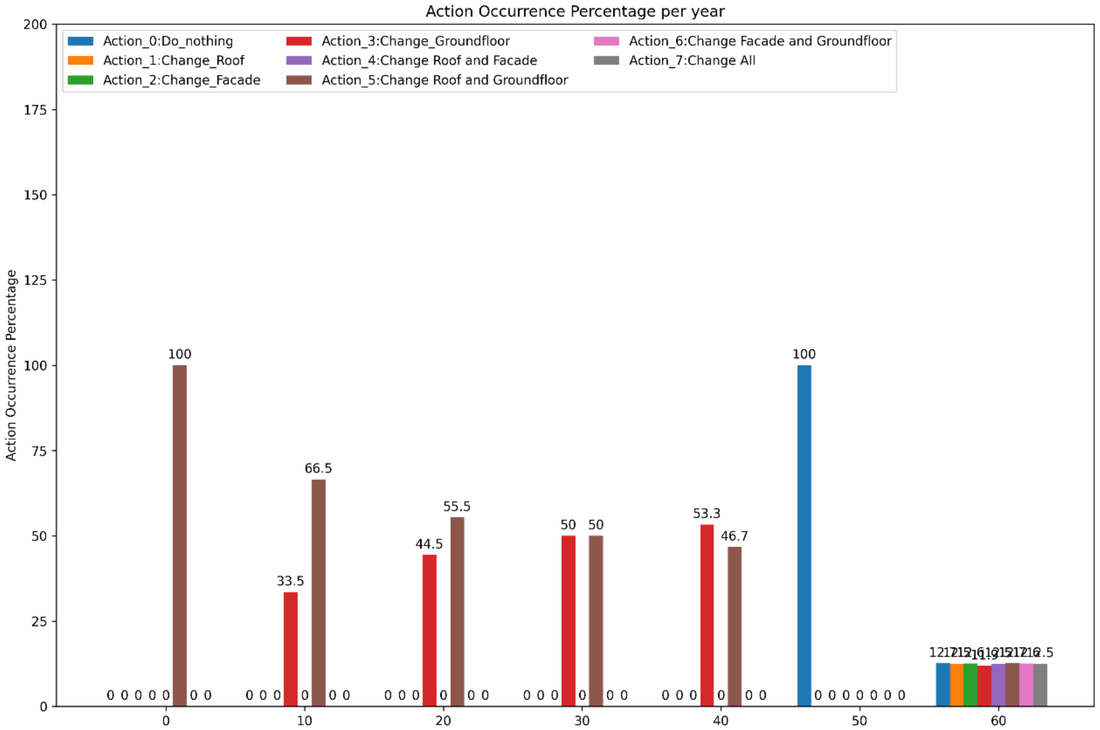












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Conclusions

- Model generated indicative policies
- Provided insight of future aspects of the methodology to be reformed

  → States , Actions , Transitions

  → Building Degradation model simulation
- Indicated future research areas

  → Building degradation over time

  →Correlation between physical and thermal performance degradation of components

  →Reverse engineering for building planning optimization

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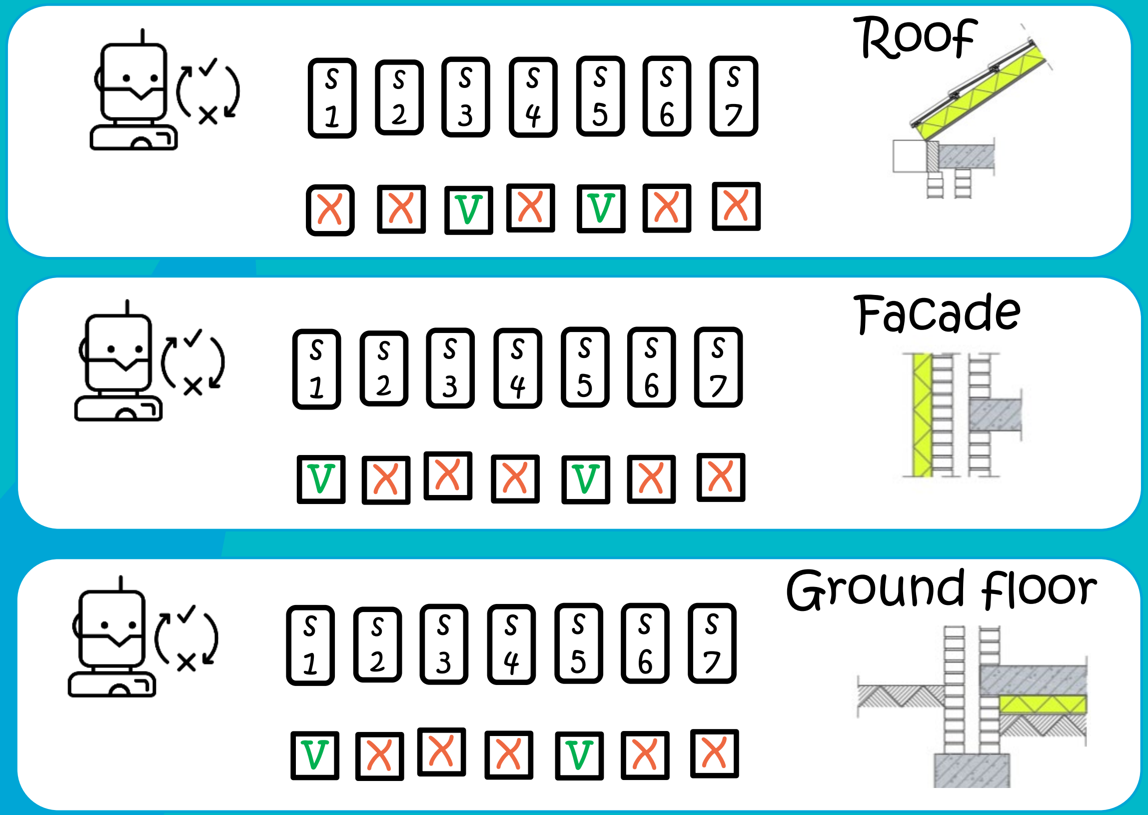
Sub Question 2

"Which algorithm should we consider for solving this problem?"

Value Iteration

Pros	Cons
• VI **will give the optimal value** function given enough iterations	• **Not good with big state** and action spaces
• **Straightforward** and **easy** to implement	• **Computationally demanding**
	• **Model based approach** meaning that requires model of the problem with all aspects involved

MARL



Sub Question 1

"How do we formulate the retrofitting planning problem as an MDP (Markov Decision Process) problem?"

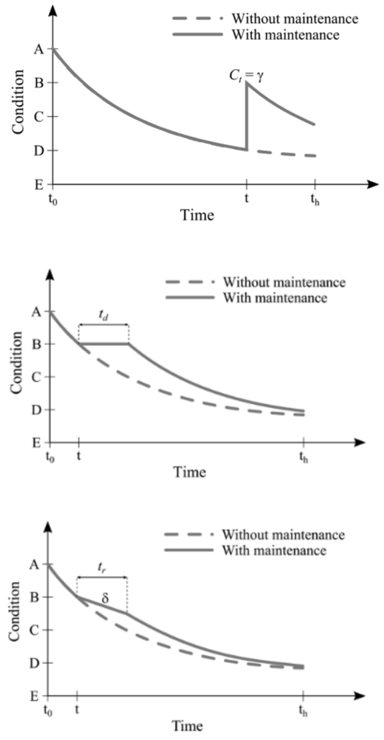
States

- Physical state of material
- Energy demand

Actions

- Minor (superficial fixes)
- Major (Change insulation)
- Deep maintenance (Apply changed to bring the building to nZEB level)

Transitions



Sub Question 3

"How can we simulate the scenario of the building components (energy) degradation?"

- Choose a building study case
- Focus on the components that usually affect the most the energy performance of the building (roof, façade, ground floor, windows, HVAC systems).
- Consider infiltration (influx of air from cracks)
- Consider external and other factors that might affect the performance
- Simulate all major scenarios and store them in data frames.

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Sub Question 4

"How do we validate the model?"

- We can do a sensitivity analysis by experimenting with rewards and policies to understand the dynamics of the environment and the policies that is giving

- Real data are needed to compare against the generated policies

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Main Question

“How can we optimize staged retrofitting planning?”

1. Define the objective function
2. Analyze important aspects based on the objective function (energy bills, retrofitting measures)
3. Analyze the factors influencing the building performance (components, infiltration, climate)
4. Simulate the different building performance scenarios
5. Use a Deep RL method

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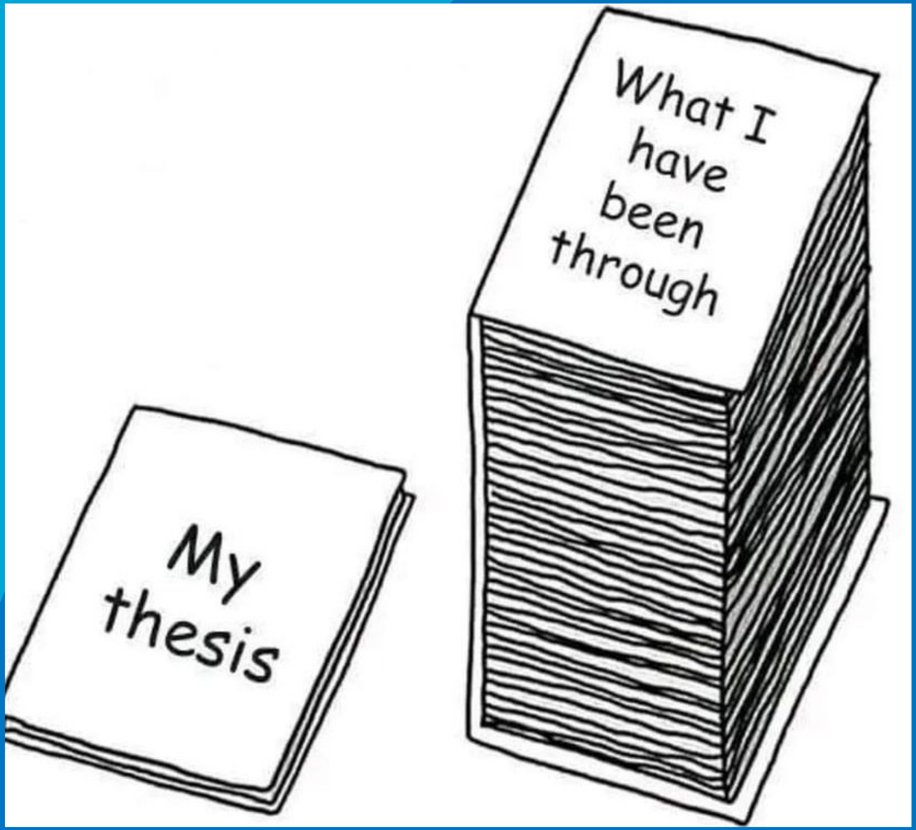

Thank you for your attention

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